Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina

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REGIONAL AQUIFER-SYSTEM ANALYSIS

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These unnamed lower Eocene sand and clay beds become progressively more argillaceous and calcareous downdip to the southeast and grade into an off-white, micritic, glauconitic, argillaceous limestone that commonly contains the foraminifer *Pseudophragmina (Proporocyclina) cedarkeysensis* Cole, a species that is found in the Oldsmar Formation in Florida. This micritic limestone, unnamed at the time of this writing, grades seaward over a short distance into a typical Oldsmar lithology. Updip, the lower Eocene clay beds are lost, and the sands become progressively less marine until they grade into a predominantly fluvial thick sand sequence that may be part of the Huber Formation (Huddlestun, 1981).

In easternmost Georgia, lower Eocene rocks consist mostly of calcareous, glauconitic, argillaceous sand, cream to gray calcareous clay, and sandy, glauconitic limestone. Locally, some of the clayey beds are dark brown and silty and contain much fine-grained organic material. Northeastward, in South Carolina, lower Eocene strata consist of sandy, fossiliferous, glauconitic limestone that has recently been named the Fishburne Formation (Gohn and others, 1983).

Depositional environments—Most of the lower Eocene rocks in the study area were deposited in shallow open marine to marginal marine environments. The laminated silty sands of the Hatchetigbee Formation were deposited in a restricted marine area, probably on tidal flats. Periodically, slightly deeper marine waters covered the tidal flats, and the Bashi Formation was deposited during such a local short-lived transgression.

Seaward of this marginal marine area, the undifferentiated thick sequence of fine clastic rocks of early Eocene age was deposited in quiet, shallow to moderately deep, open marine waters in the area that is now western panhandle Florida. Open marine conditions characterized by slightly higher energy levels existed in the central part of the Georgia coastal plain during early Eocene time, and an interbedded sequence of marine sand and clays was deposited there. This sequence, unnamed at present, grades laterally to the northeast into shallow marine sandy limestone that represents the Fishburne Formation of South Carolina.

Both the shallow water, open marine, clastic lower Eocene strata of central Georgia and the deeper water, massive clay sequence of panhandle Florida grade into and interfinger with the Oldsmar Formation. The Oldsmar was deposited in warm, shallow, open marine water and represents a carbonate bank environment. The minor evaporites found occasionally in the lower part of the Oldsmar represent sabkha conditions that were short lived and not areally extensive.

Rocks of middle Eocene age

Middle Eocene strata are present over almost all of the study area and can generally be divided into a downdip platform carbonate facies and an updip facies that is predominantly clastic. The carbonate facies of the middle Eocene extends much farther to the north and west than the carbonate rocks of the underlying early Eocene. Approximately half of the Georgia coastal plain, much of the eastern part of the Florida panhandle, and all of the Florida peninsula are underlain by middle Eocene carbonate rocks. In the remainder of the study area, the middle Eocene consists of marine to marginal marine clastic rocks.

The configuration of the top of the middle Eocene and the area where this unit crops out are shown on plate 6. Middle Eocene rocks in Alabama and southwestern Georgia are located farther gulfward than underlying rocks of early Eocene age. In contrast to this offlap relation, the lower Eocene is overlapped by middle Eocene strata in central Georgia and in South Carolina. The top of the middle Eocene is contoured to the point where the unit pinches out in its outcrop area but only to the limit of well control in eastern Georgia and South Carolina. In these areas, the middle Eocene is mostly overlapped by younger rocks.

The effect of several large-scale structural features is reflected on the middle Eocene surface. Although many of these features are recognizable on maps of the tops of older units (pls. 3, 4), their locations and shapes are different on the middle Eocene map (pl. 6). The Peninsular arch is poorly defined on plate 6, and its surface is highly irregular, probably as a result of erosion and dissolution of the top of the middle Eocene. The top of middle Eocene strata in this area is generally higher than 200 ft below sea level. The Southeast and Southwest Georgia embayments and the South Florida basin are present as low areas on the middle Eocene top, but they are not as pronounced as they are on the maps of older units. These basins were probably relatively quiescent and were being filled during middle Eocene time. The Gulf Coast geosyncline was actively subsiding during the middle Eocene, as the steep, steady gulfward slope of the top of the unit in western panhandle Florida shows. The configurations of the unnamed negative area in east-central Georgia and of the high area parallel to it in southeastern South Carolina are similar on the middle Eocene top to those on older units.

Several faults of small to intermediate throw first occurred during middle Eocene time (pl. 6). Unlike the large-displacement faults in southwestern Alabama that affect the entire column of rocks mapped for this study, most of the faults shown on plate 6 in central

Georgia and peninsular Florida appear to die out downward within the middle Eocene. An exception is the fault in Palm Beach County, Fla., which cuts rocks at least as old as Paleocene (pl. 3). The series of northeast-trending faults in south-central Georgia bounds several small grabens and half grabens that are collectively called the Gulf Trough (Herrick and Vorhis, 1963). Like most of the faults in peninsular Florida, the Gulf Trough faults appear to die out at shallow depths. A seismic profile was obtained across one of the major Gulf Trough faults in northeastern Colquitt County, Ga., as part of this study. The record on this profile is poor down to a depth of approximately 1,200 ft below land surface. Deeper than about 1,300 ft (roughly the middle of rocks of middle Eocene age), however, sharp reflectors can easily be traced on the profile and do not show the graben structure that well data prove to exist at shallower depths.

The maximum measured depth to the top of the middle Eocene is 3,490 ft below sea level in well ALA-BAL-30 in southwestern Baldwin County, Ala. The maximum contoured depth is below 3,700 ft in the same area (pl. 6). The top of the middle Eocene slopes in all directions from the crest of the Peninsular arch and reaches depths of more than 1,800 ft in the Southwest Georgia embayment, more than 1,600 ft in the South Florida basin, and more than 1,000 ft in the Southeast Georgia embayment. Middle Eocene rocks are slightly above sea level at scattered places on the Peninsular arch. They are exposed at the surface in Citrus and Levy Counties, Fla., where they represent the oldest outcropping rocks in the state.

The thickness of middle Eocene rocks is shown on plate 7, which also shows the limits of the unit's clastic and carbonate facies. The position of the interface between these facies is approximate because it is based on well control. The thickness trends shown on plate 7 have been extended in areas where well control is scattered by subtracting the contoured tops of rocks of early and middle Eocene age. From a featheredge in outcrop areas, the middle Eocene thickens seaward to more than 1,200 ft in the Southwest Georgia embayment and to more than 1,000 ft in southeastern Georgia. Along panhandle Florida's Gulf Coast, these strata are more than 900 ft thick. They thin to less than 500 ft over the crest of the Peninsular arch and thicken southward to more than 1,600 ft in east-central peninsular Florida. Although the middle Eocene is between 1,000 and 1,400 ft thick in most of southern Florida, the unit thins to less than 900 ft in part of the South Florida basin, and shows that this basin was not subsiding rapidly during middle Eocene time.

Avon Park Formation—Applin and Applin (1944, p. 1686) applied the name Avon Park Limestone to the upper part of the late middle Eocene section in a well at the Avon Park Bombing Range in the southernmost part of Polk County, Fla. They referred to the Avon Park as "a distinct faunal unit" and described it as "mainly cream-colored, highly microfossiliferous, chalky limestone" that locally contains some gypsum and chert and that is commonly partially dolomitized. Well cuttings examined during this study show that the Avon Park is in many places composed almost entirely of dolomite. The Avon Park is thus referred to in this report as a "formation" rather than a "limestone."

The term Lake City Limestone was introduced by Applin and Applin (1944, p. 1693) for the lower part of rocks of middle Eocene age in a well at Lake City in Columbia County, Fla. The Lake City was described as "alternating layers of dark brown and chalky limestone"; gypsum and chert are present in some wells. Regionally, the lower part of the middle Eocene, like the upper part, contains much dolomite.

In the early 1940's, there were few deep wells in Florida, and the samples from many of these wells were either contaminated or incomplete. Electric logging was a new technique at the time, and those few logs that were in existence were largely unreliable. A common practice in subsurface stratigraphy was to use paleontologic and lithologic units interchangeably. All of these factors led to imprecise definitions for most of the limestone units of Florida. Between some adjacent "formations," lithologic change is subtle; in places, there is no change at all. Stratigraphic breaks in much of the Florida section currently are based upon a change in the benthic microfauna that the rocks contain. Where dolomitization has obliterated the microfauna, or where it is lacking in nondolomitized sections, correlations are inconsistent. Although most workers studying the Florida subsurface recognize the problem, almost all Tertiary limestone correlations are still made on the basis of the microfaunal assemblages that Applin and Applin (1944) and Applin and Jordan (1945) thought were diagnostic. This practice is, of course, not in accordance with the rules of the current North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Units that are in reality biostratigraphic units have been mapped as if they were rock-stratigraphic units. Fortunately, as Winston (1976), recognized, the paleontologically defined units of Applin and Applin (1944) in many cases coincide with lithologic units. Exceptions to this generalization are the Avon Park and Lake City Limestones.

There are no lithologic criteria that can be used to separate the middle Eocene carbonate rocks in Florida and in southern Georgia. Both the so-called Avon Park and Lake City Limestones consist primarily of cream, tan, or light-brown, soft to well-indurated limestone that is mostly pelletal but is locally micritic. The pellets consist of fine to coarse sand-sized particles of micritic to fine crystalline limestone and small- to medium-sized Foraminifera; they are bound by a micritic to finely crystalline limestone matrix. The limestone is thinly to thickly interbedded with cream or light- to dark-brown, fine to medium crystalline, slightly vuggy dolomite, fractured in some places, whose texture is locally sucrosic to argillaceous. Locally, differences exist between the general lithologic character of the lower part of the middle Eocene and that of its upper part. Unfortunately, two of the limited number of wells available to the Applins (the Avon Park Bombing Range and Lake City wells) showed such contrasts, and it was on the basis of the limited data then available that the Avon Park and Lake City were named and extended regionally. More recent drilling shows conclusively that the rock types that the Applins thought were representative of their "Lake City" are found in many places at the top of the middle Eocene (in their "Avon Park" part) and the reverse is also true.

Paleontologic criteria by which the Avon Park and Lake City can be differentiated are lacking. In the original definition of both the Avon Park and the Lake City, certain faunal zones by which these units could be recognized were listed. The Lake City was thought to extend from the highest occurrence of *Dictyoconus americanus* (Cushman), accompanied by *Fabularia vaughani* Cole and Porter, down to the highest occurrence of *Helicostegina gyralis* Barker and Grimsdale, thought to characterize the Oldsmar. None of these species is restricted to the horizon for which it is supposed to be characteristic. *H. gyralis* commonly occurs several hundred feet above a typical Oldsmar lithology. In this study, *Fabularia vaughani* has been found at or just below the top of the middle Eocene—in the "Avon Park" part. *Dictyoconus americanus* has been reported by Cole (1944, 1945) and by Vernon (1951) from the upper part of the middle Eocene. The author has found several additional species that were listed as diagnostic Lake City Foraminifera by Applin and Jordan (1945) within 20 to 50 feet of the top of the uppermost middle Eocene. These species include *Discorbis inornatus* Cole, *Fabularia gunteri* Applin and Jordan, and *Gunteria floridana* Cushman and Ponton. Cole and Gravell (1952) found several supposedly diagnostic Lake City species in the same beds as supposedly diagnostic Avon Park species in the outcropping middle Eocene of Cuba. The Avon Park was originally defined by Applin and Applin (1944) as extending from the highest occurrence of *Coskinolina floridana* Cole downward to the top of *Dictyoconus americanus*. As Applin and Applin (1944, p. 1687), recognized, however, that *Coskinolina floridana* is abundant in the Oligocene Suwannee Limestone in many places.

The so-called Avon Park and Lake City Limestones cannot be distinguished from each other on the basis of either lithology or fauna, except locally. Therefore, it is here proposed that the term "Lake City" be abandoned and that all of the cream to brown pelletal limestone and interbedded brown to cream dolomite of middle Eocene age in peninsular Florida and southern Georgia be placed in the Avon Park Formation. The term "Avon Park" is retained because (1) it has precedence over the term "Lake City," (although both the Avon Park and the Lake City were named in the same report by Applin and Applin (1944), the Avon Park was described on an earlier page in that paper) and (2) the term has traditionally been applied to rocks whose lithology is different from that of the overlying Ocala Limestone. The Avon Park is more properly called a "formation" rather than a "limestone" because it contains appreciable amounts of rock types other than limestone. The extended definition of the Avon Park Formation proposed here refers to the sequence of predominately brown limestones and dolomites of various textures that lies between the gray, largely micritic limestones and gray dolomites of the Oldsmar Formation and the white foraminiferal coquina or fossiliferous micrite of the Ocala Limestone.

The reference section proposed for the extended Avon Park Formation is the interval from 221 to 1,190 ft below land surface in the Coastal Petroleum Company's No. 1 Ragland well in sec. 16, T. 15 S, R. 13 E, in Levy County, Fla. Cuttings from this well are on file at the Florida Bureau of Geology, Tallahassee, Fla., as well W-1537 or permit number 66. The well is numbered FLA-LV-4 in this report. A lithologic description of the cuttings from the proposed type well is given in the Appendix of this report. The top of the Avon Park is not known in the type well because there is a gap in the cuttings from the basal Ocala at a depth of 110 ft to the uppermost Avon Park sample at 221 ft. Figure 5 shows a representative electric log pattern for the Avon Park Formation (extended) in a nearby well in Levy County, Humble's No. 1 C. E. Robinson (well FLA-LV-5 of this report).

Fauna considered characteristic of the revised Avon Park Formation include the Foraminifera *Spirolina coreyensis* (Cole), *Lituonella floridana* (Cole), *Discorbis inornatus* Cole, *Valvulina cushmani* Applin and Jordan, *V. martii* Cushman and Bermudez, *Fabularia vaughani* Cole and Ponton, *Textularia coreyensis* Cole, *Gunteria floridana* Cushman and Ponton, *Pseudorbitolina cubensis* Cushman and Bermudez, *Amphistegina lopeztrigoni* Palmer, and *Lepidocyclina antillea* Cushman (formerly called *L. gardnerae* Cole). Fragments of the alga *Clypeina infundibuliformia* Morellet and Morellet are also considered characteristic of the Avon Park.

To the north and west, the Avon Park Formation grades into an argillaceous, soft to semi-indurated, micritic, glauconitic limestone that in turn grades updip into calcareous, glauconitic, often shelly sand and clay beds that are parts of the Lisbon and Tallahatta Formations. The middle third of the revised Avon Park Formation in the eastern half of the Florida peninsula and in much of southeastern Georgia is micritic, low-permeability, finely pelletal limestone. Approximately the lower half of the extended Avon Park in west-central peninsular Florida consists of low-permeability dark-colored gypsiferous limestone and dolomite. Both the micritic limestone and the gypsiferous carbonate beds comprise important subregional confining units within the Floridan aquifer system.

Tallahatta Formation—Where the Tallahatta Formation crops out in western Alabama, it consists largely of greenish-gray, porous, fine-grained siliceous claystone (called buhrstone in older reports) and some interbedded sands that are calcareous and fossiliferous near the top of the unit. In eastern Alabama, the outcropping Tallahatta is mostly poorly sorted, occasionally gravelly sand interbedded with greenish-gray clay and calcareous sand near the top. In southwestern Georgia, the outcropping Tallahatta is somewhat more marine than it is in Alabama and consists of fine- to coarse-grained slightly fossiliferous sand interbedded with dark-brown, silty, micaceous, occasionally glauconitic limestone. Chert is common near the base of the Tallahatta in updip areas in Georgia.

Downdip, in both Alabama and Georgia, the Tallahatta consists largely of interbedded gray to greenish-gray glauconitic sand and greenish-gray to brownish-gray shale; light- to dark-brown glauconitic fossiliferous limestone is common. Farther seaward in Georgia, the Tallahatta grades into cream to light-gray glauconitic, argillaceous, somewhat sandy limestone that in turn grades into the revised Avon Park Formation. Along and just to the north of the Gulf Coast of Alabama and western panhandle Florida, the Tallahatta consists mostly of gray to greenish-gray clay and thin to moderately thick interbeds of fine-grained, glauconitic, calcareous sand. Neither the limestone facies nor the calcareous clay and sand of western Florida and southern Alabama can be distinguished from similar overlying strata that are considered to be the Lisbon Formation in this study. In northeastern Georgia, the Tallahatta is mostly gray, calcareous, fossiliferous clay and has a thin sequence of calcareous sand and glauconitic limestone at the base. These strata grade northeastward into calcareous shelly sand

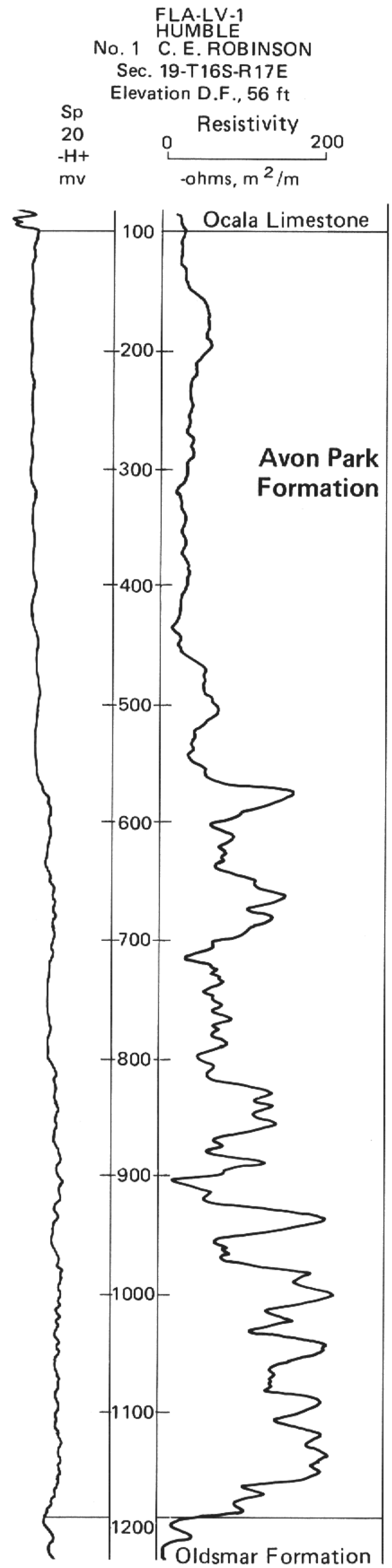

Figure 5. Representative electric log pattern for the Avon Park Formation.

and clay beds that are parts of the Congaree Formation and the Warley Hill Marl of South Carolina.

Lisbon Formation—In its outcrop area in southwestern Alabama, the Lisbon Formation consists of interbedded calcareous, glauconitic sand, sandy clay, and clay, all of which are dark green to greenish gray and fossiliferous. Carbonaceous clays commonly occur near the middle of the Lisbon in this area. In central Alabama, the outcropping Lisbon is mostly sand. Farther eastward, in southeastern Alabama and southwestern Georgia, the composition and appearance of Lisbon in outcrop are similar to those of the Lisbon in southwestern Alabama, except that the strata are somewhat lighter in color. Downdip, in southern Alabama and panhandle Florida, the Lisbon grades into gray, greenish-gray, or light-brown calcareous, glauconitic clay that contains thin to thick beds of fine-grained, calcareous, glauconitic sand and hard, sandy, glauconitic limestone. In this area contiguous to the Gulf Coast, the Lisbon cannot be differentiated from the Tallahatta.

To the east, the undifferentiated Lisbon-Tallahatta sequence grades into light-gray, glauconitic, argillaceous, somewhat sandy limestone that in turn grades into the Avon Park Formation. This light-colored, fine-grained limestone is also found throughout Georgia in a middip position between the calcareous clastic rocks of the outcropping or updip Lisbon and the pelletal Avon Park Formation. Like the Lisbon-Tallahatta sequence along the Gulf Coast, this limestone facies cannot be split into "Tallahatta" and "Lisbon" components.

In northeastern Georgia, the Lisbon consists mostly of light-gray argillaceous limestone and is underlain by clastic strata that are Tallahatta equivalents. To the northeast, the lower part of the argillaceous limestone becomes sandy, fossiliferous, and glauconitic and grades into the Warley Hill Marl of South Carolina. The upper part of the argillaceous limestone grades into the Santee Limestone of South Carolina, a slightly coarser, soft, cream to yellow, fossiliferous limestone that contains minor beds of glauconitic sand and clay.

Fauna considered characteristic of the undifferentiated clastic Lisbon-Tallahatta sequence in the study area include the Foraminifera *Asterigerina texana* (Stadnichenco), *Ceratobulimina stellata* Bandy, and *Globorotalia bullbrooki* Bolli. The ostracode *Leguminocythereis petersoni* Swain is also commonly found in these clastic middle Eocene strata.

Gosport Sand—In western Alabama, the uppermost part of the middle Eocene sequence consists of fine- to coarse-grained, glauconitic, fossiliferous sand and some beds of dark-colored shale. This unit, called the Gosport Sand, is thought to be local because it is not recognizable either in outcrop in central Alabama or in downdip wells. The strata called "Gosport" in the Savannah, Ga., area by Counts and Donsky (1963) are included in the undifferentiated Lisbon-Tallahatta sequence of this report because their lithology is completely unlike that of the Gosport even though their stratigraphic position is the same.

McBean Formation—In northeast Georgia and in South Carolina, fine-grained, loose to semiconsolidated, slightly fossiliferous sand of middle Eocene age occurs locally. This sand, called the McBean Formation, grades downward and seaward into calcareous clay that in turn grades into the upper part of the Santee Limestone. Like the Gosport, the McBean is of only local importance in the study area.

Depositional environments—The outcropping Tallahatta and Lisbon Formations were deposited in shallow marine to marginal marine environments. Transgression of the sea during the middle Eocene was more extensive than it was during either Paleocene or early Eocene time. Shallow marine Lisbon-Tallahatta rocks extending to the shore of the present Gulf of Mexico show that the middle Eocene sea floor sloped very gently there and that shallow marine waters extended over a wide area.

The Avon Park Formation, like the Oldsmar and Cedar Keys Formations, was deposited on a shallow, warm-water carbonate bank. Some of the evaporites that characterize the lower parts of the revised Avon Park Formation in west-central peninsular Florida may have formed in a tidal flat or sabkha environment.

The Congaree, Warley Hill, and Santee beds of South Carolina were deposited as the result of a single continuous transgression (Pooser, 1965). The Congaree represents basal clastic deposits. The Warley Hill was laid down in very shallow marine waters, and the Santee was deposited in a shallow shelf, open marine environment.

The Gosport Sand represents a regressive shallow marine to marginal marine deposit that was laid down as the middle Eocene sea withdrew. The McBean likewise represents a regressive sand.

Rocks of late Eocene age

Upper Eocene rocks underlie practically all of the study area, except for local areas in peninsular Florida where they have been removed by erosion. In contrast with older Tertiary units, strata of late Eocene age consist of carbonate rocks throughout all of the study area except (1) in updip outcrop locales where they interfinger with clastic materials or have been weathered into a clayey residuum and (2) in western Alabama and much of the Florida panhandle, where the upper Eocene section consists mostly of fine clastic sediments. The late Eocene represents the most extensive and widespread transgression of Tertiary seas in the Southeastern United States.

The extent, configuration of the top, and area of outcrop of rocks of late Eocene age are shown on plate 8. In Alabama and the southwesternmost corner of Georgia, these rocks are found farther gulfward than the middle Eocene strata that they overlie in offlap relation. From Stewart County, Ga., northeast, however, upper Eocene strata overlap older beds. This onlap relation extends into part of South Carolina.

From an altitude of more than 400 ft above sea level in their area of outcrop in Georgia and South Carolina, upper Eocene beds generally slope gently seaward (pl. 8). This slope is interrupted in northern peninsular Florida by a widespread high area upon which the top of upper Eocene rocks rises to altitudes slightly above sea level. This high area has been called the Ocala uplift, but it is not a true uplift. Even though this feature appears as a high on the upper Eocene top, it is not a structural high on the tops of older units (compare pl. 8 with pls. 3, 4, and 6). The upper Eocene may be high on the Ocala "uplift" because of either (1) deposition of an anomalously thick section of upper Eocene rocks in this area, (2) differential compaction, or (3) postdepositional erosion. The Ocala "uplift," regardless of its origin, is not related to the Peninsular arch. The fact that the effect of the Peninsular arch is not apparent on maps of the top of upper Eocene or younger rock shows that the arch ceased to be an active structure after middle Eocene time.

Some of the major structural lows in the study area, however, continued to actively subside during late Eocene time. Plate 8 shows a steep slope on the upper Eocene top in westernmost panhandle Florida and southern Alabama that reflects the influence of the Gulf Coast geosyncline. The negative area in Gulf and Franklin Counties in panhandle Florida is the Southwest Georgia embayment, and the low centered in Glynn County, Ga., is the Southeast Georgia embayment. The South Florida basin is also shown on plate 8 as a low area in southwestern peninsular Florida. The poor definition of the unnamed low area in east-central Georgia and its contiguous high in South Carolina (pl. 8) indicate that these features were not active "warps" in the late Eocene.

There are a number of small- to medium-sized faults shown on plate 8 that first occur in the late Eocene. Most of these are in central and northern peninsular Florida. Like the Gulf Trough graben system (running northeast across central Georgia on pl. 8), which affects only middle Eocene and younger rocks, these faults in central and northern Florida appear to be shallow features that die out with depth. The locations of the small faults are better known, and the topography shown on plate 8 for the upper Eocene top is more deatailed than that shown for deeper horizons because upper Eocene strata provide a prolific source of ground water and are therefore more intensively drilled than older units.

Upper Eocene rocks crop out more extensively than any other Tertiary unit except the Miocene. In much of their updip outcrop area, they consist largely of calcareous clastic rocks. In southwestern Georgia, easternmost Alabama, and contiguous counties in Florida, uppermost Eocene rocks consist of soft to well-indurated limestone that has a thin to moderately thick (less than 10 to more than 50 ft) clayey residuum developed on it. This residuum masks and subdues the karst topography that drilling shows is developed on the limestone surface there. In western peninsular Florida, upper Eocene sediments consist mostly of highly fossiliferous, soft limestone that shows a highly irregular, karstic, often cavernous surface resulting from extensive dissolution of the rock. Locally, in parts of the Florida peninsula, upper Eocene rocks have been completely removed by erosion, and rocks of middle Eocene age are exposed through the late Eocene surface (pl. 8).

The maximum measured depth to the top of the upper Eocene is about 3,380 ft below sea level in well ALA-BAL-30 in southern Baldwin County, Ala. The maximum contoured depth is about 4,000 ft, just to the southwest of this well. The top of rocks of late Eocene age is more than 1,000 ft below sea level in the Southwest Georgia embayment, more than 700 ft in the Southeast Georgia embayment, and more than 1,200 ft in the South Florida basin. In north-central Florida, the upper Eocene top is at or slightly above mean sea level over a wide area and slopes seaward in all directions from this high. Locally, the upper Eocene top has been vertically displaced as much as 300 ft across some of the small faults that cut the unit.

The thickness of upper Eocene strata is shown on plate 9. In contrast with older Tertiary units, upper Eocene beds are comprised of carbonate rocks almost everywhere. Most of the contouring on plate 9 is based on well-point data. In areas of sparse well control, the thickness of rocks of late Eocene age has been estimated by subtracting contoured structural surfaces of the middle and upper Eocene (pls. 6, 8). The upper Eocene is generally 200 to 400 ft thick, with two major exceptions. In the Southwest Georgia embayment, these rocks are more than 800 ft thick, and in the central part of peninsular Florida, they are less than 100 ft thick in an area that trends east-west across the peninsula. There is much local variation in the thickness of the upper Eocene because of the effects of erosion and (or) dissolution of these rocks, especially in and near the places where they crop out.

OCALA LIMESTONE—Dall and Harris (1892) applied the name Ocala Limestone to the limestone exposed in quarries near Ocala in Marion County, Fla. These rocks were incorrectly correlated with strata in Alabama that were thought then to be Eocene but that are now known to be of Oligocene age. Cooke (1915) was the first to assign the Ocala to its correct upper Eocene stratigraphic position. Applin and Applin (1944) divided the Ocala into upper and lower members. This twofold division of the formation is still used by the U.S. Geological Survey at the time of this writing (1984). However, the Florida Bureau of Geology considers the Ocala to be a group consisting of, in ascending order, the Inglis, Williston, and Crystal River Formations, as Puri (1953b) proposed.

Puri's three formations cannot be recognized lithologically even at their type sections and cannot be differentiated in the subsurface. This author does not consider the Inglis, Williston, and Crystal River Formations to be either readily recognizable nor mappable, and the terms are not used in this report. As Applin and Applin (1944) recognized, the Ocala consists in many places of two different rock types. The upper part of the Ocala is a white, generally soft, somewhat friable, porous coquina composed of large Foraminifera, bryozoan fragments, and whole to broken echinoid remains, all loosely bound by a matrix of micritic limestone. This coquina is the typical Ocala of the literature and comprises much of the formation. The lower part of the Ocala consists of cream to white, generally fine grained, soft to semi-indurated, micritic limestone containing abundant miliolid remains and scattered large foraminifers. Locally, in southern Georgia, the lower part of the Ocala is slightly glauconitic. This lower fine-grained facies of the Ocala is not everywhere present and may locally be dolomitized wholly or in part. In southern Florida, the entire Ocala is composed of micritic to finely pelletal limestone in places. Because the twofold division of the Ocala is not everywhere recognizable and because the lower micritic unit is thin where it occurs, the two members are not differentiated in this report.

The Ocala Limestone is found throughout Florida (except where it has been locally removed by erosion) and underlies much of southeastern Alabama and the Georgia coastal plain. The Ocala is one of the most permeable rock units in the Floridan aquifer system. The surface of the formation is locally very irregular as a result of the dissolution of the limestone and the development of karst topography. Locally, the upper few feet of the Ocala in the subsurface consist of white, soft, clayey residuum. Where the formation is exposed at the surface, such residuum may also be present (as in southwestern Georgia), but the clayey material is ocher to red there owing to the oxidation of the small amounts of iron that it contains.

Fauna considered characteristic of the Ocala Limestone include the Foraminifera *Amphistegina pinarensis cosdeni* Applin and Jordan, *Lepidocyclina ocalana* Cushman, *L. ocalana floridana* Cushman, *Eponides jacksonensis* (Cushman and Applin), *Gyroidina crystalriverensis* Puri, and *Operculina mariannensis* Vaughn. Although the foraminiferal genus *Asterocyclina* is not restricted to the late Eocene, it usually is not found above the top of the Ocala in the study area. The Ostracoda *Cytheretta alexanderi* Howe and Chambers and *Jugosocythereis bicarinata* (Swain) are found in shallower water parts of the Ocala as well as in its clastic equivalents.

MOODYS BRANCH FORMATION—In western panhandle Florida, the Ocala thins and, although the upper part of the formation retains its typical coquinoid character, the lower part grades westward into soft gray clay and minor interbedded fine-grained sand. This lithology is correlative with the outcropping Moodys Branch Formation of western Alabama, which consists of greenish-gray, calcareous, glauconitic sand and clay and a few layers of sandy limestone.

YAZOO CLAY—The upper part of the Ocala in central Alabama grades northward and westward through a white, massive, fine-grained, clayey, glauconitic limestone into the outcropping Yazoo Clay in western Alabama and eastern Mississippi. The Yazoo can be locally divided into four members (Murray, 1947), (from oldest to youngest): (1) the North Twistwood Creek Clay, a bluish-gray, sandy, slightly calcareous, fossiliferous clay; (2) the Cocoa Sand, a yellowish-gray, fine- to medium-grained, massive, fossiliferous sand; (3) the Pachuta Marl, a light greenish-gray, clayey, fossiliferous, calcareous sand or sandy limestone; and (4) the Shubuta, a light-gray to white, calcareous, fossiliferous, sandy clay. These divisions of the Yazoo can be traced in the subsurface for only a short distance downdip from their area of outcrop.

Fauna considered to characterize the Yazoo Clay, its middip equivalents, and the basal clastic part of the Ocala in the Florida panhandle include the Foraminifera *Bulimina jacksonensis* Cushman, *Robulus gutticostatus cocoaensis* (Cushman), and *Globigerina tripartita* Koch. Ostracoda that characterize these beds include *Cytheretta alexanderi* Howe and Chambers, *Clithocytheridea caldwellensis* (Howe and Chambers), *C. garretti* (Howe and Chambers), *Jugosocythereis bicarinata* (Swain), and *Haplocytheridea montgomeryensis* (Howe and Chambers). The latter species ranges downward into middle Eocene beds but does not occur above the top of the upper Eocene.

Barnwell Formation—The lower part of the Ocala Limestone grades laterally into more clastic rocks in northeastern Georgia. In the Savannah area, much of the lower part of the Ocala consists of light-brown, highly sandy, glauconitic, argillaceous limestone. This unit, unnamed at present, grades in turn to the north into the outcropping Barnwell Formation of eastern Georgia and southwestern South Carolina. The updip Barnwell consists of fine- to coarse-grained, gray, yellow, pink, and red arkosic sand and thin beds of light-gray to green, glauconitic, fossiliferous clay.

In parts of eastern Georgia, the Barnwell is divided into (1) a thin and locally occurring basal sand (possibly equivalent to the Clinchfield Sand), (2) a green to gray, sandy, locally glauconitic clay member (Twiggs Clay Member), and (3) an upper, massive, red, medium- to coarse-grained, locally clayey sand (Irwinton Sand Member). The Clinchfield sand and the members of the Barnwell Formation can be traced only a short distance downdip, where they grade into calcareous, argillaceous rocks that in turn grade seaward into the lower part of the Ocala Limestone.

Cooper Formation (lower members) and equivalent rocks—The upper part of the Ocala grades northward, by the addition of calcareous clay and the loss of large foraminifers, into a soft, white, argillaceous, sandy, slightly glauconitic, bryozoan-rich limestone that is the basal part of the Cooper Formation of South Carolina and northeastern Georgia. In South Carolina, the Cooper is divided into three members (Ward and others, 1979), the lower two of which are of late Eocene age. The uppermost member of the Cooper is of Oligocene age and is discussed in the Oligocene section of this report.

The basal Harleyville Member of the Cooper is a soft, clayey, micritic limestone that contains small amounts of glauconite and pyrite. A phosphate-pebble conglomerate is commonly found at the base of the Harleyville Member. The middle unit of the Cooper is the Parkers Ferry Member, a glauconitic clayey limestone that is highly fossiliferous. The Parkers Ferry Member represents the uppermost part of the late Eocene in South Carolina. The Cooper Formation is not subdivided in Georgia. Most of the Cooper in outcrop and in the shallow subsurface of Georgia is lithologically similar to the Parkers Ferry Member of South Carolina.

The updip equivalent of the Cooper Formation in Georgia is a medium- to coarse-grained, locally argillaceous and pebbly, massive red to reddish-brown sand. This unit, called the Tobacco Road Sand by Huddlestun and Hetrick (1978), is thought to be a marginal marine (lagoonal or estuarine) equivalent of the Cooper Formation. The Tobacco Road is of local importance only and is not recognizable in the subsurface.

Few cores or cuttings from wells that penetrated either the Barnwell Formation or the Cooper Formation and its equivalents were examined during this study. Although these strata are known to contain a sparse to well-developed microfauna in places, no species has been identified during this study as being characteristic of these formations.

Depositional environments—Practically all the rocks of late Eocene age in the study area were deposited in shallow, open to marginal marine environments. The Ocala Limestone was deposited in warm, shallow, clear water on a carbonate bank that was probably similar to the modern Bahama Banks. The basal part of the Ocala in western panhandle Florida and the Moodys Branch Formation, which is its updip equivalent, as well as the Yazoo Clay represent marginal marine (lagoon or estuary) to shallow, open-shelf conditions.

The Barnwell Formation and the Tobacco Road Sand were deposited in estuarine, sound, or lagoonal conditions. The Cooper Formation that lies downdip from these units represents shallow water, open marine conditions. The basal phosphate conglomerate of the Harleyville Member of the Cooper was deposited during transgression of the late Eocene sea.

OLIGOCENE SERIES

Rocks of Oligocene age are found over approximately two-thirds of the study area and occur in two separate large bodies. The more extensive area underlain by Oligocene rocks is a wide band that extends seaward from the outcrop of these rocks in Alabama, Georgia, and South Carolina. A second, somewhat smaller area of Oligocene strata covers the southwestern quarter of the Florida peninsula. Plate 10 shows the extent of these two main bodies of Oligocene rocks, the area where Oligocene strata crop out, and the configuration of the Oligocene surface. Throughout the study area, Oligocene rocks are in offlap relation to the upper Eocene and lie seaward of these older beds (compare pls. 8 and 10). Where Oligocene rocks are overlapped by Miocene sediments, the updip limit of the Oligocene is approximate because it is based on available well data; this approximate limit is shown as a dashed line on plate 10. The Oligocene Series consists of carbonate rocks throughout all of the study area except for southwestern Alabama, western panhandle Florida, and parts of northeastern Georgia and southwestern South Carolina, where clastic strata make up an important part of the Oligocene. The few scattered outliers of Oligocene lying between the two main bodies shown on plate 10, indicate that these rocks extended over a much wider area before being removed by erosion. Older rocks are exposed at scattered places within the widespread but generally thin body of the Oligocene in Georgia, where erosion has removed all of the Oligocene locally. The locations of most of the Oligocene outliers and the places where Oligocene rocks have been stripped are based on well data compiled for this study. A few of these features, however, are located from published sources, and thus lie in places where no well control is shown on plate 10. Erosional remnants to the north and west of the general updip limit of the Oligocene show that these rocks once extended over a much wider area.

Both large- and small-scale structural features affect the configuration of the Oligocene top. Large-scale features include (pl. 10) (1) the steep gulfward slope of the unit in southwestern Alabama, which reflects subsidence of the Gulf Coast geosyncline, (2) the low area in southern Gulf County, Fla., that represents the Southwest Georgia embayment, (3) the negative area in Glynn County, Ga., and adjacent counties that is the Southeast Georgia embayment, and (4) a low area in southwestern peninsular Florida that may represent a remnant of the South Florida basin. The northwest-southeast orientation of the axis of the South Florida basin is different from its alinement on the surface of older rock units (compare, for example, pls. 8 and 10). The high area shown on the Oligocene surface along the Gulf of Mexico parallel to the South Florida basin is not present on the upper Eocene top. This high probably acted as a sill or barrier during Oligocene time and partly restricted open circulation between the South Florida basin and the ocean. Smaller structural features shown on plate 10 include the northeast-trending series of small grabens in central Georgia that are collectively called the Gulf Trough and a coast-parallel normal fault that extends from Indian River County southeast through Martin County, Fla. The Oligocene has been eroded from the upthrown side of this fault but is preserved on its downthrown side.

The Oligocene top slopes generally seaward from a high of more than 300 ft above sea level in the unit's outcrop area in central Georgia to slightly more than 600 ft below sea level in both the Southwest and Southeast Georgia embayments. This general seaward slope is interrupted in northern Florida by a high area extending from Leon County eastward to Columbia County, where Oligocene rocks crop out. From a second outcrop area that extends southward from Citrus to Hillsborough Counties, Fla., Oligocene rocks slope into the South Florida basin, where the Oligocene top is more than 900 ft below sea level. The maximum measured depth to the top of the Oligocene is about 2,680 ft below sea level in well ALA-BAL-30 in southern Baldwin County, Ala. The maximum contoured depth is below 3,200 ft, to the southwest of this well. Although the top of the Oligocene is affected locally by erosion and karst topography, it is not as irregular as the top of upper Eocene strata.

The thickness of the Oligocene Series is shown on plate 11. Most of the contouring shown on this plate is based on well data. Where wells are scattered, the thickness of Oligocene rocks has been estimated by subtracting contours that represent the tops of upper Eocene and Oligocene rocks (pls. 8 and 10). Oligocene strata are generally less than 200 ft thick in the study area. Exceptions are southwestern Florida, where these rocks are more than 400 ft thick; southern Gulf and Franklin Counties, Fla., where they are more than 600 ft thick; and the southernmost part of Alabama, where they are more than 800 ft thick. These thick areas represent the South Florida basin, the Southwest Georgia embayment, and the northeastern rim of the Gulf Coast geosyncline, respectively. Throughout most of eastern Georgia and all of South Carolina, the thickness of the Oligocene Series only locally exceeds 100 ft and is generally 50 ft or less.

Suwannee Limestone and equivalent rocks

The name "Suwannee Limestone" was proposed by Cooke and Mansfield (1936, p. 71) for "yellowish limestone typically exposed along the Suwannee River in Florida, from Ellaville...almost to White Springs...." They considered these beds to be of Oligocene (Vicksburgian) age rather than Miocene as previous investigators had postulated. Cores and well cuttings examined during this study show that the Suwannee usually consists of two rock types: (1) cream to tan, crystalline, highly vuggy limestone containing prominent gastropod and pelecypod casts and molds and (2) white to cream, finely pelletal limestone containing small foraminifers and pellets of micrite bound by a micritic to finely crystalline limestone matrix. Although these two rock types are complexly interbedded in places, the pelecypod cast-and-mold limestone is more characteristic of the upper part of the Suwannee and is the lithology most representative of the entire formation in most of Georgia and eastern panhandle Florida. The micritic pelletal limestone that is characteristic of the lower part of the Suwannee is locally found higher in the formation in southwestern Florida. Because the Suwannee, like the Ocala, cannot be divided everywhere, the two facies have not been delineated in this report.

The upper part of the Suwannee has been locally silicified, and this chert-rich horizon was named the Flint River Formation in Georgia. These silicified beds are rarely found in the subsurface and appear to merely represent local diagenetic conditions rather than a widespread mappable variation within the Suwannee. The term Flint River is accordingly not considered to be a valid formational name in this report.

The upper part of the Suwannee in the Georgia subsurface commonly consists of medium to coarsely crystalline, light-brown to honey-colored, saccharoidal, vuggy dolomite. The erosional remnants of Suwannee preserved as outliers several miles distant from the main bodies of Oligocene rocks (pl. 10) and consisting of either limestone or dolomite show that marine Oligocene strata once covered the entire study area. Locally, the cast-and-mold facies of the Suwannee contains fine-grained sand. Very locally, the micritic pelletal facies contains trace amounts of fine- to medium-grained, light- to dark-brown phosphate. In outcrop, the Suwannee locally weathers to a nodular, rubbly surface owing to the removal of layers, lenses, and stringers of soft argillaceous limestone.

The Suwannee grades northward in northeastern Georgia and South Carolina into part of the Cooper Formation by the addition of clay and sand and the loss of limestone. Westward, across panhandle Florida and southern Alabama, the Suwannee appears to grade into the lower part of the Bucatunna Formation. In that area, the Suwannee consists of tan limestone, dolomitic limestone, and light-colored calcareous clay. Some of these beds were called "Byram" or "Glendon" by early workers (Cooke and Mossum, 1929; Cooke, 1945) primarily on the basis of their stratigraphic position. Some faunal aspects of the Suwannee in Florida are Chickasawhayan (late Oligocene); others are Vicksburgian (early Oligocene). The unit is thus interpreted in this report as spanning both ages (pl. 2). The Suwannee in Georgia is thought to be late Oligocene (Huddlestun, 1981).

Microfauna considered characteristic of the Suwannee include the larger Foraminifera *Lepidocyclina leonensis* Cole and *L. parvula* Cole as well as the small Foraminifera *Pararotalia byramensis* Cushman and *P. mexicana mecatepecensis* Nutall, which are closely related. Although the genus *Miogypsina* ranges into younger strata in the central Gulf Coast, it does not occur above the top of the Suwannee in the study area. The larger Foraminifera *Discorinopsis gunteri* Cole, *Dictyoconus cookei* (Moberg), and *Coscinolina floridana* Cole are commonly found in the Suwannee, but these three species are also found lower in the section in the middle Eocene Avon Park Formation. Some authors think that these species have been reworked from the Avon Park into the Suwannee. Others think that they are merely long-ranging species that are "facies seekers." That is, their reappearance in the Suwannee means nothing more than the reestablishment of environmental conditions like those in which the Avon Park was deposited. Most individuals of these three species from the Suwannee examined during this study appeared fresh and unaltered, and the species are widespread throughout the cast-and-mold facies of the formation. In addition, there is no apparent Avon Park source from which these fossils could have been reworked. The isolated patches of Avon Park that are exposed through a cover of upper Eocene sediments (pl. 8) are too small and too scattered to provide a source from which these widely distributed Foraminifera could have been reworked into the Suwannee. This author therefore believes that these are long-ranging species indigenous to the Suwannee Limestone.

Bumpnose, Red Bluff, and Forest Hill Formations

In panhandle Florida, the Oligocene Series thickens considerably (pl. 11) and becomes increasingly clastic westward. In addition, some carbonate units that are older than the Suwannee are present at the base of the Oligocene (pl. 2). One such unit is the Bumpnose Formation, a name applied by Moore (1955) to a soft, white, somewhat glauconitic, highly fossiliferous (pelecypod and gastropod casts and molds and bryozoan and foraminiferal remains) limestone that crops out in central Jackson County, Fla. Moore thought that the Bumpnose represented the uppermost part of the late Eocene but recognized that many of its faunal elements were Oligocene. Subsequent work by Hazel and others (1980) confirmed the findings of MacNeil (1944) and Cooke (quoted by Moore, 1955, p. 38) that the beds that Moore called Bumpnose correlate with the Red Bluff Formation of Alabama of known Oligocene age. The Bumpnose in its type area is very likely a transitional unit between the late Eocene and early Oligocene. The Bumpnose Formation, however, is placed in the Oligocene in this report because carbonate rocks in western Alabama that are in the same stratigraphic position as the Bumpnose and that can be shown to correlate with it are of Oligocene age (Hazel and others, 1980).

The Bumpnose grades northwestward into the Red Bluff Formation, which is mostly dark-gray to brown, fossiliferous, glauconitic clay that contains some iron-rich beds and siderite concretions, and local beds of glauconitic, sandy, fossiliferous limestone. The Red Bluff in turn grades westward into the Forest Hill Formation, a dark-colored silt, sand, and clay sequence that is highly lignitic near its top and base. Gulfward, the Bumpnose merges with the basal part of a thick sequence, unnamed at present, of interbedded pelletal limestone, micritic limestone, and tan, finely crystalline dolomite. To the southwest across the Florida panhandle, the Bumpnose pinches out in western Bay County, Fla. The Red Bluff and Forest Hill Formations are recognizable in the subsurface only a short distance downdip of their outcrop.

Mint Spring and Marianna Formations

The Marianna Formation is a soft, cream to white, highly fossiliferous (mostly large foraminifers), glauconitic limestone that is argillaceous in places. The amount of clay in the Marianna increases northwestward across southern Alabama as the Marianna grades into the Mint Spring Formation, a thin, fossiliferous, glauconitic sand or clayey sand that represents the base of the Vicksburg Group in western Alabama (Hazel and others, 1980). Gulfward from its type area in central Jackson County, Fla., the Marianna becomes part of a thick unnamed sequence of Oligocene limestone and dolomite beds. Like the Bumpnose, the Marianna pinches out to the southwest in western Bay County, Fla. The Mint Spring is not recognizable in the subsurface.

Glendon Formation

The Glendon Formation is a thin, fossiliferous, cream-colored limestone that occurs in the updip Oligocene of western Alabama. The Glendon is not recognizable in the subsurface in downdip areas of southern Alabama and panhandle Florida and is not thought to crop out in Florida. The micritic, pelletal, lower part of the outcropping Suwannee Limestone at its type locality was once thought to be equivalent to either the Glendon (Cooke and Mossum, 1929) or the Byram (Cooke, 1945). This report considers these beds to be part of the Suwannee.

Byram Formation

The Byram Formation in its outcrop area in western Alabama consists of light-colored, sandy, glauconitic, calcareous clay and some beds of sandy, white, fossiliferous limestone. The Byram is thin in outcrop and appears to merge with the Bucatunna Formation in the shallow subsurface by loss of limestone and increase of clay. In some publications, the terms Glendon and Byram appear to have been used somewhat interchangeably.

Bucatunna Formation

To the west of eastern Walton County and western Bay County, Fla., the basal unit of the subsurface Oligocene is a massive, light- to medium-gray, calcareous, fossiliferous clay containing trace amounts of fine sand. This unit, called the Bucatunna Formation, has a distinctive low-resistivity electric log pattern and constitutes one of the most easily recognizable stratigraphic markers in westernmost Florida and southern Alabama. Updip, the Bucatunna is less marine and consists of dark-colored carbonaceous silt, bentonitic clay and thin interbeds of yellow sand. The Bucatunna forms an excellent confining bed, separating permeable limestones of late Eocene age (Ocala) from late Oligocene limestone strata that are also highly permeable. The Bucatunna merges updip with more sandy or calcareous Oligocene beds and passes by facies change eastward into an unnamed thick sequence of limestone and dolomite beds of Oligocene age in eastern panhandle Florida.

Chickasawhay Formation

The uppermost part of the Oligocene Series in southern Alabama and much of panhandle Florida consists of white, micritic to pelletal, hard to semi-indurated, fossiliferous limestone and thin to thick beds of light- to dark-brown, fine to medium crystalline, vuggy dolomite. This unit is thought to be equivalent to the outcropping Chickasawhay Formation of western Alabama. The Chickasawhay in outcrop consists of bluish-gray, soft, glauconitic, calcareous clay and some beds of white fossiliferous limestone. The Chickasawhay can be distinguished in the subsurface as far east as central Bay County, Fla., where it grades into unnamed interbedded Oligocene limestone and dolomite that in turn thin and grade northward and eastward into the upper part of the Suwannee Limestone.

The Paynes Hammock Formation, a thin, calcareous, fossiliferous sand and clay sequence that overlies the Chickasawhay, cannot be distinguished from the Chickasawhay in the subsurface, and the two are thus not separated in this report.

In most of the subsurface of the western third of the study area, Oligocene strata can be divided into the basal Bucatunna Formation and the upper Chickasawhay Formation. Fauna considered to characterize these two units include the Foraminifera *Pulvinulina mariannensis* Cushman, *Robulus vicksburgensis* (Cushman) Ellisor, *Palmula caelata* (Cushman) Israelsky, and *Globigerina selli* (Borsetti). The ostracode *Aurila kniffeni* (Howe and Law) is also considered characteristic of these strata.

Cooper Formation (Ashley Member)

The uppermost part of the Cooper Formation, called the Ashley Member by Ward and others (1979), is of Oligocene age, in contrast to the late Eocene age of the lower two members of the Cooper. The Ashley Member consists of brown to tan, soft, calcareous, clayey sand that usually contains much phosphate and glauconite and carries a rich microfauna. The thickness of the member is highly variable. To the south and southeast, the Ashley Member grades into the Suwannee Limestone by the addition of impure limestone beds and the loss of clastic strata. The microfauna of the Cooper were not examined in enough detail during this study to determine which species are characteristic of any of the formation's members, including the Ashley. However, the foraminifer *Pararotalia mexicana mecatepcensis* Nutall was identified from the upper part of the Cooper in several wells in northeastern Georgia.

Chandler Bridge Formation

The Chandler Bridge Formation (Sanders and others, 1982) is a thin sequence of clayey phosphatic sand beds that unconformably overlies the Ashley Member of the Cooper Formation. Chandler Bridge beds occur locally and appear to be preserved only in low areas on the Ashley surface. The Chandler Bridge contains no microfauna and is dated Oligocene on the basis of its stratigraphic position and the primitive aspect of its cetacean fauna, which somewhat resembles forms found in the upper Oligocene of Europe.

Depositional environments

The Suwannee Limestone and the equivalent thick sequence of unnamed interbedded limestone and dolomite in eastern panhandle Florida were deposited in a carbonate bank environment. The part of the Cooper Formation that is of Oligocene age (Ashley Member) and the Chandler Bridge Formation that overlies it were laid down in a marginal marine environment. All of the Oligocene units in Alabama and those in updip areas of panhandle Florida were deposited in shallow marine to restricted marine (lagoonal or estuarine) environments. The formations that are mostly limestones (Bumpnose, Marianna, and Glendon) formed in shallow, warm, open marine waters. Those units that are highly argillaceous and glauconitic (Red Bluff, Mint Spring, Byram, and Chickasawhay) are estuarine to lagoonal for the most part but may grade into shallow shelf, open marine deposits downdip. The dark-colored clays that are part of the Forest Hill and the updip portion of the Bucatunna are mostly lagoonal but in places may represent deltaic conditions. The Bucatunna and Forest Hill represent local regressive phases of the generally transgressive Oligocene sea.

MIOCENE SERIES

Rocks of Miocene age underlie most of the study area except for a wide band in northwestern peninsular Florida, where they have largely been removed by erosion. These strata are mostly clastic, with the exception of (1) sandy limestone that comprises the Tampa Formation and its equivalents and (2) dolomite beds that commonly make up the lower part of the Hawthorn Formation. Miocene rocks crop out over more of the study area than any other Tertiary unit and are highly dissected in outcrop and shallow subcrop locales. The paleogeography of the eastern Gulf Coast was very different in Miocene time than it had been before. The carbonate bank environment that characterized peninsular Florida and adjacent areas during most of Tertiary time was covered during the Miocene by an influx of clastic sediments. Chemical conditions in parts of the Miocene ocean were also quite different and resulted in the widespread deposition of phosphatic and siliceous sediments, especially during middle Miocene time.

The extent and the configuration of the surface of the Miocene Series is shown on plate 12, along with the area where these rocks crop out. Over more than half of their extent, Miocene rocks are at or above sea level. The contour interval used on plate 12 is smaller than that used on maps of the structural surfaces of older units to better portray the irregular topography developed on the top of the Miocene. The rough surface of the unit and the numerous small outliers preserved as erosional remnants apart from the main body of Miocene rocks show that the Miocene surface has been deeply eroded. At a few scattered places within the main body of Miocene rocks, older units are exposed where the Miocene has locally been completely eroded through.

In outcrop areas in Alabama and Georgia, Miocene rocks are found at altitudes of more than 300 ft above